THERMAL PERFORMANCE OF "ENERGY-EFFICIENT" METAL STUD WALL SYSTEMS

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ABSTRACT

Metal stud wall systems for residential building are gaining in popularity. Very strong thermal bridges caused by highly conductive metal studs worsen the thermal performance of such walls. Several wall configurations have been developed to improve their thermal performance. In this paper the authors evaluate some of these wall systems.

A series of ASTM C 236 hot-box tests and two- and three-dimensional computer simulations were conducted for several metal stud walls. A finite-difference computer code was used to model walls and their details. Maps of the temperature distribution in walls, their components, and the areas where walls intersect with other building structures were developed. These maps were used as an aid to estimate the areas of zones affected by existing thermal bridges and to calculate R-values for these areas. These R-values were then used to calculate average overall wall (whole-wall) R-values, which include the thermal effect of all wall details. Using simulated R-values, several configurations of wall insulation and metal frame structural details were examined.

Metal components in metal stud walls can create significant thermal bridges, which can lead to excessive heat transfer for building walls. At present, most thermal calculations for metal stud systems are based on the measured or calculated thermal performance of the flat wall area without the effect of the wall details included. In this paper, this method is called the "clear wall" method. The clear wall is understood as the part of the wall that is free of thermal anomalies due to wall details (i.e., window or door perimeters) or intersections with the other building surfaces.

Since metal frame buildings can have a reduced R-value caused by metal studs, the thermal efficiency of insulation in metal stud walls can also be reduced. Several authors estimated the range of R-value reduction due to metal studs at 30% to 50% of "in cavity" thermal resistance (excluding metal elements). Since the amount of the R-value reduction caused by metal studs can be different for different metal frame walls, terms for the apparent thermal resistivity of insulation and framing effect were introduced to measure the effectiveness of use of insulation material.

INTRODUCTION

Metal stud wall systems for residential buildings are gaining in popularity. Unfortunately, because the metal components in the walls can create significant thermal bridges, such walls, if not suitably designed, could lead to excessive heat transfer for building walls. Two series of metal stud walls have been monitored. For the first wall series, hot-box tests and computer modeling were performed. For the second, where more complicated wall configurations were included, only two- and three-dimensional computer modeling were used. In this study, thermal properties of 18 metal frame walls with various configurations of insulation and various metal stud sizes and spacing were examined experimentally and analytically.

It was observed that installing additional exterior sheathing insulation is an effective way to improve the thermal performance of the metal frame panels. For all the walls examined, the layer of 1.0 in. (2.5 cm) of expanded polystyrene (EPS) sheathing [R = 4.0 $h \cdot ft^2 \cdot {}^\circ F\ (Btu)^{-1}$ – (0.7 $m^2 \cdot K/W$)] increased wall R-value by about 5 $h \cdot ft^2 \cdot {}^\circ F\ (Btu)^{-1}$ (0.9 $m^2 \cdot K/W$). Changing stud spacing from 16 in. (40 cm) to 24 in. (60 cm) o.c. increased wall R-value by about 8% for a wall without exterior EPS sheathing. Installing simple wooden washers (creating a thermal break) increased wall R-value from 13% to 16% for different levels of exterior EPS sheathing. In wall configurations using wooden washers to separate two rows of metal studs (3½-in. and 1½-in.), wall R-value increased up to 16 $h \cdot ft^2 \cdot {}^\circ F (Btu)^{-11}$ (2.8 $m^2 \cdot K/W$) for a wall without exterior EPS sheathing and insulated by a 6.5-in. layer of mineral fiber.

Since metal frame buildings can have a reduced R-value, the thermal efficiency of insulation in metal stud walls can also be reduced. Several authors estimated the range of R-value reduction due to metal studs (framing effect) at 30% to 50% of the thermal resistance of the layers of wall materials used ("in cavity" R-value excluding metal elements) (Brown and Stephenson 1993; Trethowen 1988). The authors have introduced methods for estimating framing effect and actual thermal resistivity of

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insulation material. These methods may be used in the design of wall technologies and in the analysis of thermal performance of wall systems.

At present, most thermal calculations for metal stud systems are based on the measured or calculated thermal performance of the flat wall area without the effect of wall components included. In this paper, that method is called the "clear wall" method (the clear wall is the part of the wall that is free of thermal anomalies due to wall subsystems or intersections with other building surfaces). The temperature distribution in walls, in their components, and in the areas where walls intersect with other building structures was monitored. The temperature maps were used as an aid to estimate the areas of zones affected by existing thermal bridges and to calculate R-values for these areas. These R-values were then used to calculate average R-values for whole walls and the estimation of the thermal effects of wall details. For metal stud wall systems, most wall details have 50% lower R-values than clear wall areas. It was observed that a change in wall detail configuration can notably affect proportions in wall area distribution and overall wall R-value. For an "ideal" wall system, the local thermal resistances created by wall details should be at least as "good" as for the clear wall area. Heat losses through details should be proportional only to the wall area distribution. Considering that only about 70% of the wall area in a metal stud system represents a clear wall, and that any change in the configuration of wall details can affect overall wall R-value, the "clear wall" method is obviously inadequate for use in the thermal analysis of metal stud buildings.

THERMAL TESTS OF METAL STUD WALL SYSTEMS

Measurements of wall systems are typically carried out by apparatus such as the one described in ASTM C 236 (ASTM 1989). A relatively large (approximately 8 ft by 8 ft or larger) cross section of the clear wall area of the wall system is used to determine its thermal performance. Thermal anomalies such as metal studs are typically included in the tested configuration. The precision of this test method is reported to be approximately 8% (ASTM 1989).

At a national laboratory, a series of three metal stud walls with thermal breaking systems was tested in the guarded hot box. Also, the results for an additional three metal stud walls (previously tested) were used for vali-

TABLE 1 **Configurations of Tested Metal Stud Walls**

Wall Symbol	Size of Stud	Cavity Insulation	Exterior/ Interior Surface Finish	Additional Insulation	Source of Test Results
A1	3-5/8"- 18 GA (9.2-cm.-thickness 0.12-cm.) 24-in. (60-cm.) o.c.	R-11 Fiberglass Batts (paper-faced)	0.64-in. Gypsum board	no	A. McGowan, A.O. Desjarlais
A2	same	same	same	0.94-in. (2.39-cm.) of EPS sheathing	A. McGowan, A.O. Desjarlais
A3	same	same	same	1.45-in. (3.68-cm.) of EPS sheathing	A. McGowan, A.O. Desjarlais
B1	same	same	same	0.67-in. (1.7-cm.) air-cavity created by 1x2 furring-strips installed horizontally with 24-in. (60-cm.) o.c.	present paper
B2	same	R-11 Fiberglass Batts (reflective foil-faced)	same	0.67-in. (1.7-cm.) air-cavity created by 1x2 furring-strips installed horizontally with 24-in. (60-cm.) o.c.	present paper
B3				R-8 fiber-glass batts installed in cavity created by furring-strips installed horizontally with 24-in. (60-cm.) o.c. plus 1.5-in. (3.8-cm.) studs attached to furring-strips vertically with 24-in. (60-cm.) o.c.	present paper

TABLE 2 **Thermal Properties of Wall Materials for Metal Stud Walls Tested**

Wall Material	Thermal Conductivity (Btu·in./h·ft^2·°F)	Thermal Conductivity (W/m·K)
1. Metal	484.00	69.8
2. Gypsum wallboard 0.64-in. (1.63-cm.)	1.32	0.190
3. 1-in. EPS 0.96-in. (2.44-cm.) wall A2	0.257	0.037
4. 1.5-in. EPS 1.45-in. (93.68-cm.) wall A3	0.269	0.039
5. R-11 paper-faced fiberglass walls: A1, A2, A3, B1	0.309	0.045
6. R-11 reflective foil-faced fiberglass walls: B2, B3	0.321	0.046
7. Unfaced fiberglass—additional insulation at wall B3	0.272	0.039
8. Wood spacers—furring-strips, walls: B1, B2, B3	0.84	0.121

dation of a computer model and as an aid in wall performance thermal analysis (McGowan and Desjarlais 1995). These configurations and material properties are presented in Tables 1 and 2. In Table 3, the measured R-values of these walls are presented.

THERMAL MODELING OF METAL STUD WALLS

A finite-difference computer code developed by a national laboratory was used to analyze the thermal fields in metal stud walls, wall subsystems, and areas of intersection with other building elements (Childs 1993). Multiple materials and time- and temperature-dependent thermal conductivity, density, and specific heat can be considered. The boundary conditions, which may be surface-to-environment or surface-to-surface, may be specified temperatures or any combination of prescribed heat flux, forced convection, natural convection, and radiation. Two-dimensional modeling was performed for most of the clear wall areas. Three-dimensional modeling was necessary for one clear wall configuration, wall details, and areas of wall intersection with other building structure components. Maps of temperatures obtained as a result of the modeling were used to calculate average heat fluxes and wall R-values.

The accuracy of the computer modeling approach was verified by the authors using several published reports of test results for masonry, wood frame, and metal stud walls (Kosny and Desjarlais 1994; Barbour et al. 1994). Also, results of hot-box tests performed on six metal stud walls were used. The statistics of the comparison between experimental and simulated R-values are presented in Table 4.

The discrepancy between results was computed for each case by the following formula:

$$\text{Discrepancy} = \left[\frac{R_{simul} - R_{test}}{R_{test}}\right] \cdot 100\% \qquad (1)$$

where

R_{test} = test resulted R-value and

R_{simul} = R-value obtained as a result of computer simulation.

All tests mentioned in Table 4 were realized by means of the guarded hot box method. Considering that the precision of the guarded hot box method is reported to be about 8% (ASTM 1989), the accuracy of Heating 7.2 modeling can be estimated within the precision of the test method.

TABLE 3 **R-Values of Metal Stud Walls Tested**

Wall Symbol	Wall Configuration	R-Value (h·ft²·°F/Btu)	R-Value (m²·K/W)
A1	Gypsum board, Studs 3-5/8 in.-18 GA (9.2-cm.-thickness 0.12-cm.), R-11 fiberglass batts, Gypsum board.	7.81	1.38
A2	0.94-in. (2.39-cm.) EPS, Gypsum board, Studs 3-5/8 in.-18 GA (9.2-cm.-thickness 0.12-cm.), r-11fiberglass batts, Gypsum board.	12.52	2.20
A3	1.45-in. (3.68-cm.) EPS, Gypsum board, Studs 3-5/8 in.-18 GA (9.2-cm.-thickness 0.12-cm.), R-11 fiberglass batts, Gypsum board.	13.85	2.44
B1	Gypsum board, 0.67-in (1.7-cm.) air cavity created by furring-stris, Studs 3-5/8 in.-18 GA (9.2-cm.-thickness 0.12-cm.), R-11 fiberglass batts, Gypsum board.	8.8	1.55
B2	Gypsum board, 0.67-in (1.7-cm.) air cavity created by furring-stris, Studs 3-5/8 in.-18 GA (9.2-cm.-thickness 0.12-cm.), R-11 fiberglass batts with reflective surface, Gypsum board.	10.03	1.77
B3	Gypsum board, 0.67-in (1.7-cm.), 1.5-in. (3.8-cm.) studs, R-8 fiberglass, air cavity created by furring-stris, Studs 3-5/8 in.-18 GA (9.2-cm.-thickness 0.12-cm.), R-11 fiberglass batts with reflective surface, Gypsum board.	15.78	2.78

TABLE 4 **Accuracy of Heating 7.2 Thermal Modeling**

Source of Information and Number of the Wall [ ] Considered	Wall Description	Discrepancy Between Results (%)
1. Valore (1988) (4)	Empty 2-core, 30 cm (12 in.) CMU	3.60
2. Valore (1988) (6)	Filled 2-core, 30 cm (12 in.) CMU	5.6
3. Van Geem (1986) (1)	Empty 2-core, 30 cm (12 in.) CMU	–0.3
4. Van Geem (1986) (1)	Filled 2-core, 30 cm (12 in.) CMU	–3.6
5. James (1990) (1)	Empty 2-core, 30 cm (12 in.) CMU	–0.9
6. James (1990) (1)	Filled 2-core, 30 cm (12 in.) CMU	0.8
7. James (1990) (1)	2x4 wood-framed wall	1.6
8. Brown (1993) (2) Strzepek (1990) (2)	metal stud walls, 16-in. (40-cm.) o.c.	5.2
9. McGowan and Desjarlais (1995) (3)	A1, A2, A3	-1.1
10. Present paper tests (3)	B1, B2, B3	2.2

TABLE 5 **Configuration and Characteristics of Metal Studs in Simulated Walls**

Wall Symbol	Size of Studs, Stud Spacing	Insulation of Wall Cavity	Exterior/Interior Surface Finish	Optional Sheathing Insulation Between Plywood and Wood Siding
C1	3-1/2 x 1-5/8-in. 18 GA (8.9 x 4.1-cm. thickness, 1.2-mm), spacing 16-in. o.c. (40-cm.)	Mineral fiber	Interior—0.5-in. gypsum board	no
C2			Exterior—05-in. plywood + optional sheathing insul. + 0.5-in. wood siding	0.5-in. (1.2-cm.) of EPS
C3				1.0-in. (2.5-cm.) of EPS
D1	3-1/2 x 1-5/8-in. 18 GA (8.9 x 4.1-cm. thickness, 1.2-mm), spacing 24-in. o.c. (60-cm.)	Mineral fiber	Interior—0.5-in. gypsum board	no
D2			Exterior—05-in. plywood + optional sheathing insul. + 0.5-in. wood siding	0.5-in. (1.2-cm.) of EPS
D3				1.0-in. (2.5-cm.) of EPS
E1	4 x 1-5/8-in. 18 GA (10.2 x 4.1-cm. thickness, 1.2-mm), spacing 24-in. o.c. (60-cm.)	Mineral fiber	Interior—0.5-in. gypsum board	no
E2			Exterior—05-in. plywood + optional sheathing insul. + 0.5-in. wood siding	0.5-in. (1.2-cm.) of EPS
E3				1.0-in. (2.5-cm.) of EPS
F1	3-1/2 x 1-5/8-in. 18 GA (8.9 x 4.1-cm. thickness, 1.2-mm), spacing 24-in. o.c. (60-cm.)	Loose-filled insulation filling all cavity	Interior—0.5-in. gypsum board	no
F2			Thermal Breaking System (1x2 wooden spacers attached horizontally to the metal studs)	0.5-in. (1.2-cm.) of EPS
F3			Exterior—05-in. plywood + optional sheathing insul. + 0.5-in. wood siding	1.0-in. (2.5-cm.) of EPS

SIMULATED METAL STUD WALLS AND THEIR DETAILS

In addition to the experimental study, four common types of metal stud walls were simulated. Three levels of insulation were included in the models for each type of wall. The total number of simulated walls reached 12. Configurations of these walls are described in Table 5.

The four basic types of simulated metal stud walls were constructed according to the descriptions available in two published documents. Walls C, D, and F were designed according to AISI (1993). In wall F, a thermal breaking system was installed. It contained 1x2 wooden spacers attached horizontally with 24-in. (60-cm.) o.c. to the metal studs. These spacers separate metal studs from the exterior sheathing. It was assumed in computer modeling that air spaces were eliminated, as loose-filled insulation filled all cavities created by metal studs and wood spacers. Walls E were "built" according to NAHB (1992).

TABLE 6 **Thermal Properties of Wall Materials for Computer Modeling**

Wall Material	Thermal Conductivity (Btu·in./h·ft^2·°F)	Thermal Conductivity (W/m·K)
1. Gypsum wallboard	1.11	0.16
2. Mineral fiber or loose-filled insulation	0.29	0.04
3. Plywood	0.80	0.12
4. Expanded polystyrene sheathing	0.25	0.04
5. Wood siding	1.23	0.18
6. Structural wood	1.00	0.14
7. Metal	333.30	47.52

For overall wall thermal analysis, nine wall details were simulated for walls C3 (AISI) and E3 (NAHB). Ceiling joist profiles were assumed to be 6 × 1¾ in. 18GA (15.2 × 4.4 cm, 1.2-mm thick) for wall C3, and 9 × 1¾ in. 16GA (22.8 × 4.4 cm, 1.5-mm thick) for wall E3. Attic floor joist profiles were assumed to be 6 × 1¾ in. 18GA (15.2 × 4.4 cm, 1.2-mm thick) for both cases.

The thermal properties of the materials were assumed to be uniform for all simulated walls to aid the evaluation analysis. They are presented in Table 6.

CLEAR WALL THERMAL PERFORMANCE OF METAL STUD WALLS

Temperature distribution maps obtained during computer modeling were used to estimate average surface heat flux for all considered walls. A knowledge of heat flux values allowed R-value calculations. Figure 1 shows all experimental R-values and R-values calculated as a result of Heating 7.2 modeling (surface-to-surface R-values and air film resistance are not included). For four types of popular walls, three levels of exterior insulation were considered. In these cases (walls C, D, and E, without exterior EPS sheathing), R-values between 7.3 and 10.2 h·ft^2·°F/Btu (1.3 and 1.8 m^2·K/W) were obtained as a result of computer modeling. It can be observed from these models that 1 in. (2.5 cm) of EPS layer with a theoretical R-value of 4.0 h·ft^2·°F/Btu (0.7 m^2·K/W) may bring to the metal stud wall an additional 5.0 h·ft^2·°F/Btu (0.9 m^2·K/W) of R-value. In walls F, the thermal breaking system was installed. This increased wall R-value 5% to 9% if compared with walls E (containing the same amount of insulation).

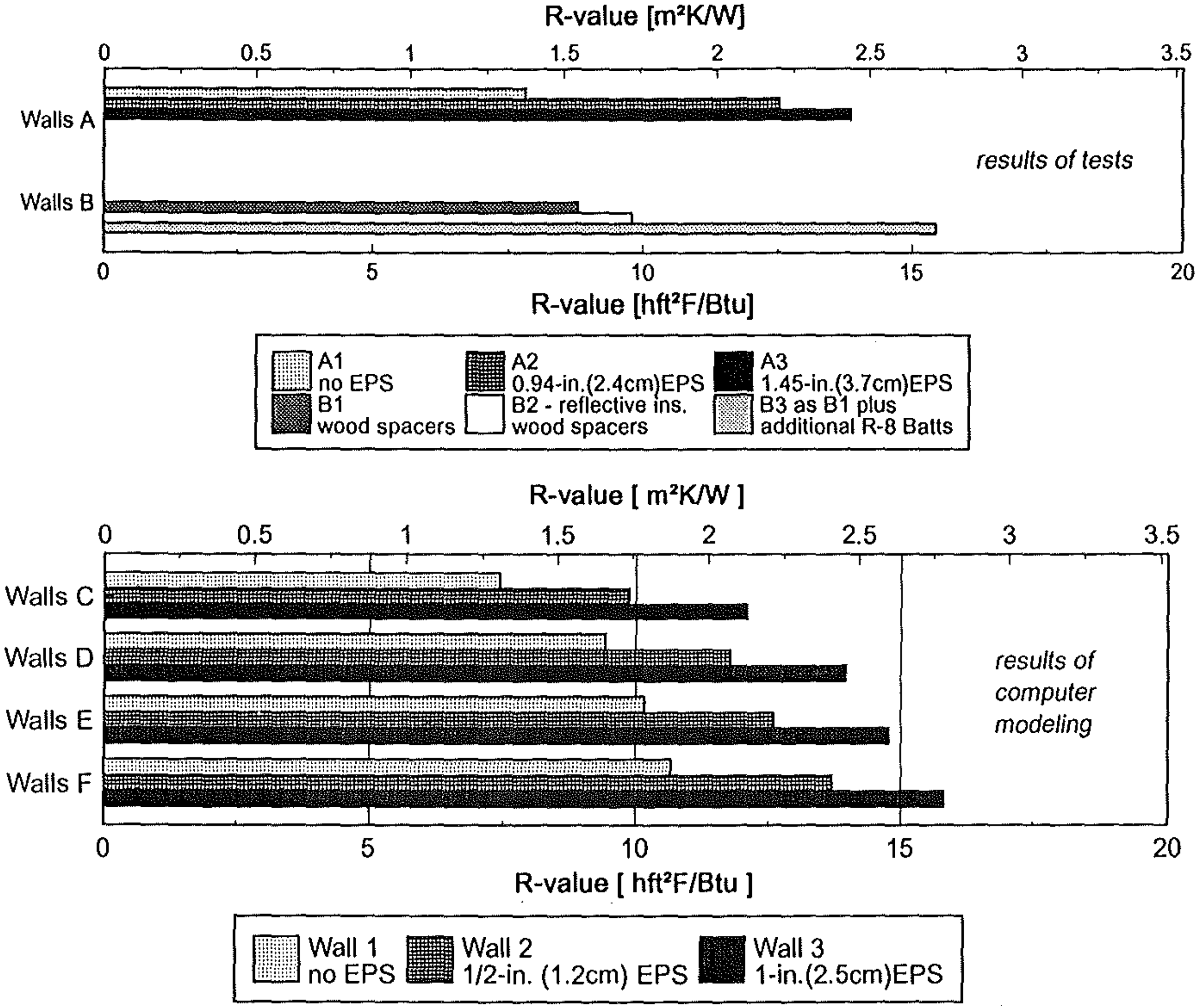

Figure 1 *Clear wall R-values for examined metal stud walls.*

For tested walls, the effect of application of a thermal breaking system (containing an air cavity) was examined. Thermal break was created by installing horizontally 1×2 wooden spacers to separate metal studs from the exterior sheathing and to create an air cavity. In wall B3 this cavity was filled by additional fiberglass insulation (R-8). Comparing wall A1 with walls B1, B2, and B3, the following increase in R-value can be observed:

- A1 vs. B1—11.9%,
- A1 vs. B2—22.5%,
- A1 vs. B3—65.7%.

In wall B3, the increase in R-value reached 7.63 $h \cdot ft^2 \cdot {}^\circ F/Btu$ (1.34 $m^2 \cdot K/W$). However, in wall B3 additional R-8 insulation was installed. Wall B2 used almost the same insulation as wall A1 (only reflective facing was added). The use of the thermal breaking system in wall B1 brought a 12% increase in R-value (compared with walls A1 and B1). When taking into account that this thermal breaking system has the same efficiency in wall B2, it may be assumed that the reflective facing of insulation used in wall B2 improved the R-value of wall B2 by an additional 10%.

Changing stud spacing from 16 in. to 24 in. o.c. (walls C and D) increased wall R-value. The highest improvement was observed at 25% for a wall without exterior EPS sheathing. The efficiency of this change decreases for the walls with additional exterior insulation. The benefit in R-value caused by the increased spacing was about 20% for walls with ½ in. (1.2 cm) of EPS and about 15% with 1 in. (2.5 cm) of EPS.

It can also be observed that additional layers of EPS sheathing of the same thickness may result in different increases in wall R-values for several wall configurations. To analyze this phenomenon, the term of apparent thermal resistivity, *ar*, was introduced. It can be described by the following equation:

$$ar = \frac{R_i - R_o}{d_i}, \quad (2)$$

where

R_o = R-value of wall without exterior sheathing,
R_i = insulated wall R-value, and
d_i = thickness of sheathing insulation.

Table 7 presents *ar* values for all cases of considered insulation and wall configurations. The highest *ar* values for simulated metal stud walls are observed for the first ½ in. (1.3 cm) of EPS sheathing. These results were generated by very strong thermal bridge effects near the metal studs. The high apparent resistivity decreases for additional layers of insulation because of more uniform temperature distribution.

Calculations and test results for metal frame walls show that the measured wall R-value can be considerably lower than the "ideal" R-value calculated, excluding the effects of thermal bridges caused by metal studs. However, those comparisons do not clearly show how effectively the wall materials are used. The data in Figure 2 depict a comparison between R-values simulated by Heating 7.2 and "ideal" R-values calculated only for layers of the used materials (excluding the metal studs). The loss of wall R-value due to the metal studs is called the *framing effect*, (*f*). It can be described by the following formula:

$$f = \left[1 - \frac{R_{simul}}{R_{ideal}}\right] \cdot 100\% \quad (3)$$

where

R_{simul} = simulated R-value and
R_{ideal} = "ideal" R-value for layers of material (in cavity R-value).

For the conventional wall with 3½-in. (8.9-cm) metal studs, 18 GA (1.2-mm thick), installed with 16 in. (40-cm) o.c., with R-12 h·ft²·°F/Btu (2.1 m²·K/W) mineral fiber insulation batts, the decrease in R-value is about 48%, which is close to similar values reported by Brown and Stephenson (1993) and Trethowen (1988).

Tested wall A2 is similar to simulated wall D3, where a similar amount of insulation was installed. The value of the framing effect (*f*) is very close for both walls (Figure 2). In wall B1, the same amount of insulation was installed as in wall A1. Additionally, wood spacers were attached to metal studs to separate studs from exterior sheathing and to create a thin air cavity. This brought a reduction in the framing effect from 38% to 30%. Wall B2 is most effective among the walls with a thermal breaking system installed. It is a result of the use of insulation with reflective facing. For wall B2, the value of the framing effect is only 20%. Wall B3 has similar thermal resistance to wall F3. However, wall F3 has a lower value of framing effect—just above 20%. In two types of walls (B and F) several options of thermal breaking systems were examined. Both types of walls perform well when compared with other walls containing similar amounts of insulation. Walls B2 and F3 have the lowest values of framing effect—only about 20%. It is important to recall that wall B2 has no sheathing insulation. The framing effect (*f*) for comparably insulated wall A1 is equal to about 38%. This indicates that installing a thermal breaking system is an effective way to improve the thermal performance of metal stud walls.

TABLE 7 **Apparent Thermal Resistivity (*ar*-Values) for All Wall Configurations Considered in Tests and Thermal Modeling**

Compared Walls	Case of Insulation Taken Into Account	*ar*-Values h·ft²·°F/Btu-In.	*ar*-Values m·K/W	Percent of Original Thermal Resistivity (%)
A1 vs. A2	0.94-in. (2.4-cm.) EPS[b]	4.71	28.32	116
A1 vs. A3	1.45-in. (3.7-cm.) EPS[c]	4.16	29.09	112
C1 vs. C2	first 0.5-in. (1.2-cm.) EPS[a]	5.66	39.60	142
C2 vs. C3	second) 0.5-in. (1.2-cm.) EPS[a]	5.02	35.10	126
C1 vs. C3	1.0-in. (2.5-cm.) EPS[a]	5.34	37.40	134
D1 vs. D2	first 0.5-in. (1.2-cm.) EPS[a]	5.04	35.20	126
D2 vs. D3	second) 0.5-in. (1.2-cm.) EPS[a]	4.48	31.30	112
D1 vs. D3	1.0-in. (2.5-cm.) EPS[a]	4.76	33.30	119
E1 vs. E2	first 0.5-in. (1.2-cm.) EPS[a]	5.14	35.90	129
E2 vs. E3	second) 0.5-in. (1.2-cm.) EPS[a]	4.46	31.20	112
E1 vs. E3	1.0-in. (2.5-cm.) EPS[a]	4.8	33.60	120
F1 vs. F2	first 0.5-in. (1.2-cm.) EPS[a]	6.4	44.80	160
F2 vs. F3	second) 0.5-in. (1.2-cm.) EPS[a]	4.26	29.80	107
F1 vs. F3	1.0-in. (2.5-cm.) EPS[a]	5.33	37.30	133

[a]For walls C1 through F3, EPS thermal resistivity was assumed as r = 4.0 h·ft²·°F/Btu per in. (28.0 m·K/W).
[b]For wall A2, r = 4.05 h·ft²·°F/Btu per in. (28.3 m·K/W).
[c]For wall A3, r = 3.71 h·ft²·°F/Btu per in. (25.9 m·K/W).

WALL AREA DISTRIBUTION IN METAL FRAME WALLS AND ITS INFLUENCE ON OVERALL WALL R-VALUE

In most building wall thermal calculations, a known (calculated or measured) R-value for the clear wall area is used. Building material producers also often use clear wall R-values as a factor that describes thermal properties of building wall systems they are selling. This practice causes misunderstanding and mistakes in predicting energy consumption for buildings because an actual building wall always contains components such as corners and structural connections with ceilings, attic insulation, and roof elements. Window and door openings also affect the thermal charac-

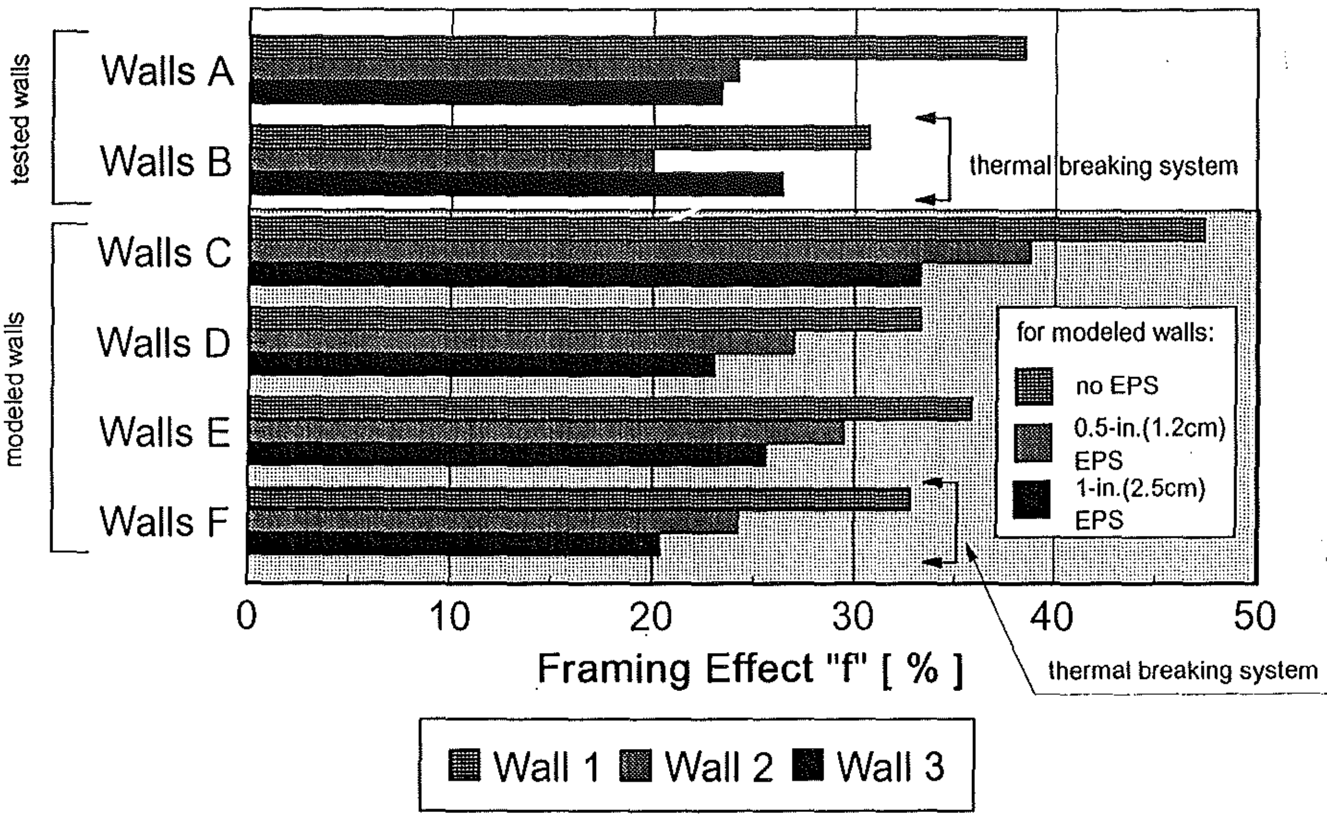

Figure 2 Reduction of R-value caused by metal studs (framing effect).

teristics of the clear wall because of their different structures. The influence of each wall component on average wall R-value is different for each house because of the different structural elements and dimensions that can be used.

In metal frame walls, metal wall components can create significant thermal bridges. Highly conductive metal elements are used mostly to create the structure of the building. So, thermal shorts are concentrated mostly around the structural joints and intersections. Because of the three-dimensional character of heat flow, it is difficult to examine them using traditional analytical tools (calculation and test methods). Those tools have been developed for clear wall areas and are useful only in analyzing simple cases of heat exchange.

Heating 7.2 was used to analyze the thermal fields in metal stud walls, wall subsystems, and areas of intersection with other building elements. Wall area was divided into the following zones:

- clear wall area,
- corner area,
- roof/wall intersection,
- ceiling/wall intersection,
- door header and side, and
- window header, side, and sill.

In this paper, two different wall detail geometries were compared—one following the AISI residential steel framing manual (AISI 1993) (walls C and D), the other following construction details of NAHB (1992) (walls E). Walls F were designed at the national laboratory.

The influence of subsystems on the overall wall thermal performance is different for every house because of the variety of architectural designs. To normalize the calculations, a standard elevation was used to combine the R-values of the various details and to compute the overall wall system thermal resistance. The standard elevation selected for this purpose is a single-story ranch-style house that has been the subject of previous energy-efficiency modeling studies (Huang et al. 1987). The house has approximately 1,200 ft^2 (111 m^2) of living area, 1,500 ft^2 (139 m^2) of exterior wall area, eight windows, and two doors. The elevation area is about 1,320 ft^2 (122 m^2), and the overall wall area is 1,146 ft^2 (106 m^2), including 154 ft^2 (14.3 m^2) of window area and 28 ft^2 (2.6 m^2) of door area.

Every wall detail was analyzed by means of two- or three-dimensional modeling. Temperature maps obtained as a result served in calculating average surface heat fluxes and then wall R-values. The amount of the clear wall area was calculated by determining the zone of influence for each subsystem and subtracting that area from the total exterior wall area. The zone of influence was determined by examining the isotherms produced by the modeling runs (Kosny and Desjarlais 1994). The area depicting isotherms influenced by the presence of a subsystem was defined as the zone of influence for that subsystem. The thermal resistance (R-value) of each wall detail was computed by dividing the average surface-to-surface temperature difference by the average heat flux. For the well-insulated metal stud walls (1-in.-thick EPS exterior sheathing), most of the detail R-values (except corners) are at least twice as low as clear wall R-values (Figure 3).

The overall thermal resistances, R_{ow}, of 1,146 ft^2 (106 m^2) of the wall in the elevation were computed for two metal stud wall configurations. Based on the computed wall detail R-values, the overall wall system R-value was calculated by combining the thermal resistances of the wall details, subsystems, wall intersections, and clear wall area in a parallel, area-weighted method:

$$R_{ow} = \left[\sum_{i=0}^{i=1}\left(w_i \cdot \frac{1}{R_i}\right)\right]^{-1} \quad (4)$$

where

R_i = R-value of wall detail (including clear wall),
i = number of wall detail, and
w_i = detail area weighting factor, where

$$w_i = \frac{\text{area of detail}}{\text{overall wall area}}. \quad (5)$$

Since thermal properties of wall details are different from those of clear wall areas, distribution of heat losses through the wall details can be different from the wall area distribution. For an ideal wall system, overall wall R-value should be equal or close to the clear wall R-value. When the R-value of a detail is lower than the clear wall R-value, this indicates that the thermal performance of this wall detail should be improved.

For the wall system using NAHB details (1-in. EPS sheathing), the overall wall R-value is 27% lower than the clear wall R-value. For a wall following AISI details (1-in. EPS sheathing), the overall wall R-value is 19% lower than for the clear wall. The wall area influenced by each detail in AISI wall systems is shown in Figure 4. For the system following AISI details, the clear wall represents 68% and all details 32% of the whole wall area. At the same time, 49% of heat losses are generated by wall details' area. This disproportion suggests that R-values of wall details are too low in the considered metal stud wall system. Changes in detail construction may affect wall area distribution and it can vary for different buildings. Thermal properties of wall details are as important as clear wall R-value. Improvement of wall details may considerably reduce heat losses in buildings constructed with metal stud walls.

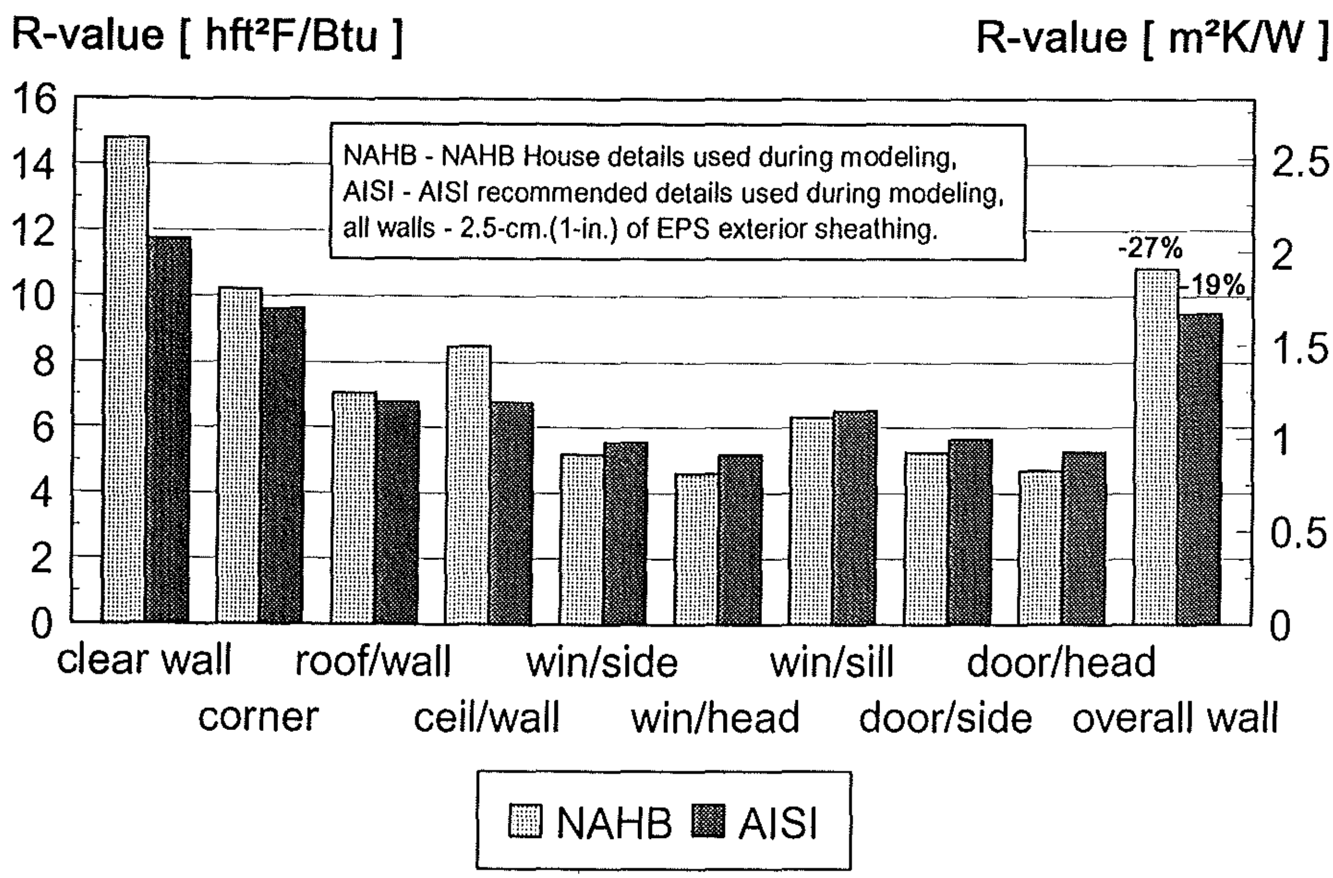

Figure 3 R-values of wall details for two metal stud wall systems.

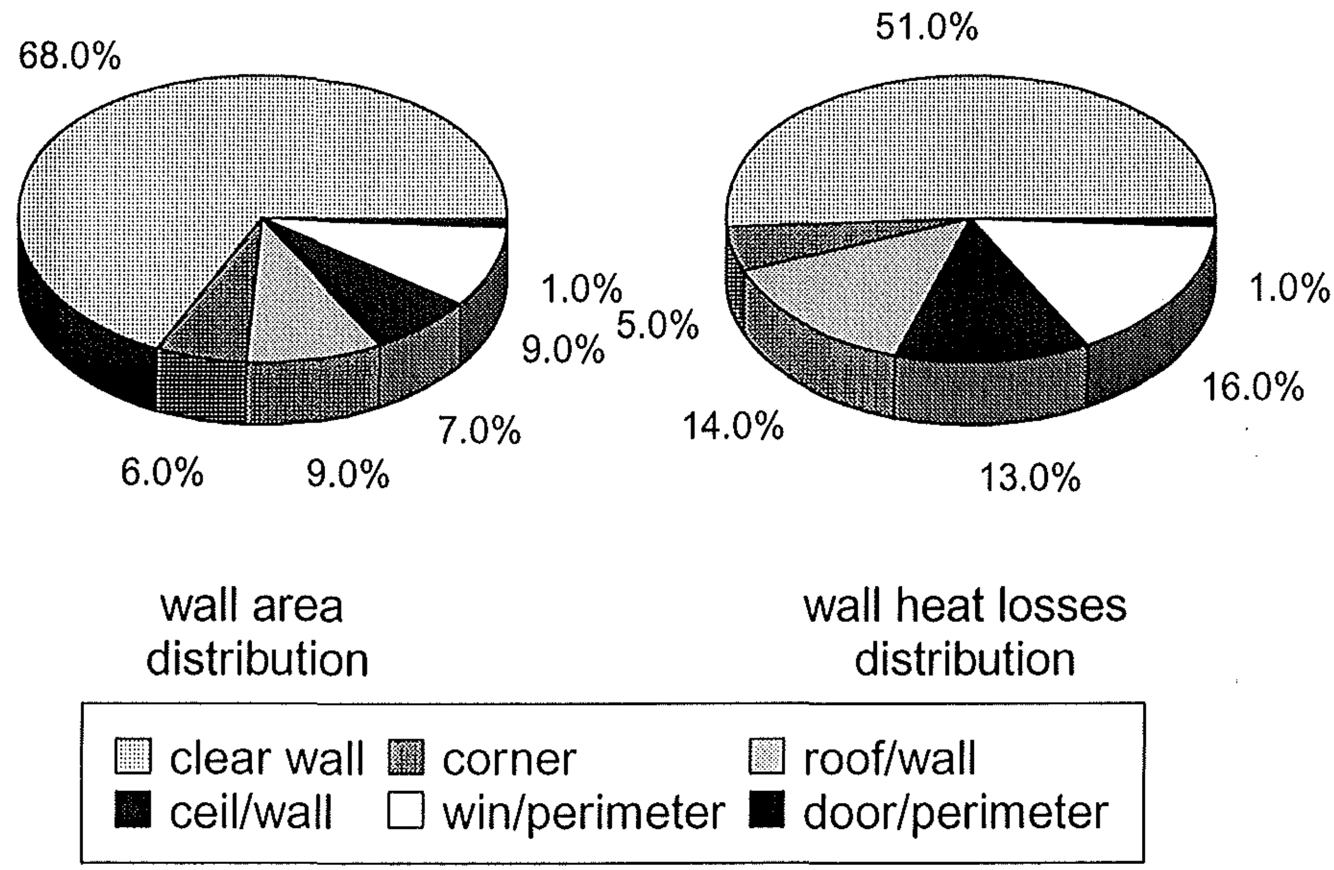

Figure 4 Analysis of distribution of wall area and heat losses throughout wall details for metal stud walls system.

CONCLUSIONS

In this study, thermal properties of 18 metal frame walls with various configurations of insulation and various metal stud sizes and spacing were examined experimentally and analytically. Also, 16 wall details were modeled for two metal stud wall systems, and an overall thermal analysis was performed. The results obtained led to the following conclusions.

- Installing additional exterior sheathing insulation is an effective way to improve the thermal performance of the metal frame walls.
- Changing stud spacing from 16 in. o.c. to 24 in. o.c. increased wall R-value by 25% for a wall without exterior EPS sheathing. The efficiency of this change decreases for walls with additional exterior insulation sheathing. The gain in R-value caused by the increased spacing was about 20% with ½ in. (1.2 cm) of EPS and about 15% with 1 in. (2.5 cm) of EPS.
- Installing 1 by 2 wooden washers (creating a thermal break) on a 3½-in. (8.9-cm) metal stud wall increased the wall R-value by about 5% to 9% compared with a 4-in. (10.2-cm) stud wall (containing the same amount of insulation).
- Wood spacers attached to the metal studs to separate studs from the exterior sheathing reduced the framing effect from 38% to 30%. For a wall with foil-faced insulation (reflective surface), the value of the framing effect was reduced to 20%. Walls with thermal breaking systems perform very well when compared to other walls containing similar amounts of insulation. The smallest values of the framing effect (about 20%) were observed for two walls from this group. This indicates that installing a thermal breaking system is a very effective way to improve thermal performance of metal stud walls.
- Changing the distance between metal studs from 16 to 24 in. (40 to 60 cm) o.c. reduced the value of the framing effect (caused by metal studs) by about 30%. However, the framing effect can also be lowered by the addition of EPS sheathing—about 30%—for walls with a 1 in. (2.5 cm) thick layer of EPS.
- For metal stud wall systems, about 70% of wall area represents a clear wall. Most of the wall details have 50% lower R-values than for clear wall areas. It was observed that a change in wall detail configuration can notably affect proportions in wall area distribution and the overall wall R-value.
- Since wall details and intersections in metal stud walls can represent about 30% of total wall area and about 50% of overall heat losses, the assumption of

100% clear wall area for wall heat transfer or building energy-use calculations is generally inadequate.

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